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Original Research

Kinematic Differences between Traditional and Sport Version of Roundhouse Kick Executed by Male Taekwon-do Masters

Jacek Wąsik[1,*], Dariusz Mosler[1], Tomasz Góra[1], Dorota Ortenburger[1], Małgorzata Chalimoniuk[1], Józef Langfort[1]

[1]Department of Kinesiology and Health Prevention, Jan Dlugosz University of Czestochowa, 42-200 Czestochowa, Poland
*Correspondence: j.wasik@ujd.edu.pl (Jacek Wąsik)
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Abstract

Background: Different competitions require mastery in different forms of technique execution, which changes their kinematics. The aim of this study was to obtain knowledge about kinematic indicators that determine the effectiveness of two versions of taekwon-do roundhouse kicks: sport and traditional. **Methods**: The analysis included 180 kicks performed by 15 male Taekwon-do masters from the International Taekwon-do Federation. The study was performed using a stereo photogrammetry method with a set called Human Motion Lab, composed of 10 infrared NIR Vicon MX-T40 cameras. **Results**: Obtained results showed, that there are significant differences in the maximal velocity and time of execution for both lower limbs ($p < 0.01$) in terms of technique version. Sport version of roundhouse kicks had shorter execution time and higher maximal velocity (0.45–0.46 s, 12.26–12.44 m/s). There were no significant differences between the left and right lower limbs for each technique. There was no significant correlation between lower limb length and maximal velocity or execution time of the kicks. **Conclusions**: Modern competitions forced the evolution of sports versions from the traditional type of execution which was confirmed by better kinematic results. The lower limb length did not determine the speed of the roundhouse kick. Taekwon-do masters can perform roundhouse kicks without significant differences between their lower limbs, which means that the lateralization effect is not present.

Keywords: kicking velocity; taekwon-do; movement analysis; kicks kinematics; traditional technique; sport kick

1. Introduction

The transition from the original use of martial arts toward modern sports competition forced the evolution of the traditional type of technique execution into sport, sparring type. Different competition types [1,2] require different versions of technique execution, which vary according to biomechanics and kinematics. In International Taekwon-do Federation (ITF), taekwon-do athletes participate in four types of competitions: sparring [3], patterns [4], power tests [5], and special techniques [6]. They mostly use traditional forms of kicks in addition to sparring. The direct confrontation of participants in the ITF is based on point acquisition by successful strikes. Knocking out opponents is forbidden in a manner similar to kickboxing or sports karate. Competition is determined using a point system. The first successful strike was mostly rewarded with points [7]. Participants who obtained more points won This system places special emphasis on speed and reflexes. A lower participant usually loses the fight. The main purpose of training is to shorten the time from detectable movement initiation to contact with the target, lowering the chance for the opponent to defend [8]. This is particularly challenging for complicated techniques and combinations using multiple techniques. It forces participants to use specific movements, which are concurrent with traditional versions of techniques unique to this martial art.

In competitions where Taekwon-do patterns are assessed, participants need to use traditional versions of techniques with rigorous requirements. The dynamics and perfection of traditional technique execution determine the winner. Another competition tests participant strength by breaking special boards. In this type of competition, the participants also need to use traditional techniques. Only a positive judgment of technique execution allows a trial to be acknowledged.

Previous studies have demonstrated that the Estevan *et al.* [9] analysed kicking techniques, but in the method description of their works, they emphasised stance. Traditionally, the rear lower limb is placed at a sharp angle to the target of 45° [9,10]. Zero degrees, so both feet are pointed toward the target and are associated with the description of the sport's stance. Other researchers have also emphasised on the stance or preferred kicking side [11]. In this work, in addition to differences in stance, we emphasised different contact areas and foot positions at the end of the movement, which was not a theme of previous works. In the sports version, the stance is not rigged—individuals can choose foot placement and angles. The contact area in sports stance is the dorsal side of the foot and full plantar flexion of the ankle joint, whereas in the traditional version, contact is made by the plantar side of the foot and full dorsal flexion of the ankle joint.

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The time of kick execution and repeatability of maximal velocity results could be used to select the best karate athletes and follow their preparation progress [12]. Assessment and knowledge of the factors that affect maximal velocity may be crucial for detecting athlete errors and improving their techniques. Disturbances in the maximal velocity repeatability of the results cannot be easily detected by the trainer's eye observations.

The roundhouse kick is the most popular technique used in competition [13]. Therefore, numerous authors in the field of sports biomechanics have aimed to extend the knowledge about this technique and contribute to a body of knowledge about it. Falco *et al*. [14] studied the influence of distance from the target and its relation to roundhouse-kick kinematics. Estevan *et al*. [15] studied the impact force and timing of the sports version of a roundhouse kick. Serina and Lieu [16] studied potential injuries inflicted by the execution of roundhouse kicks. The phenomenon of lateralisation and its influence on roundhouse kick kinematics were studied by Cular *et al*. [3]. Lower-limb kinematics during the execution of roundhouse kicks are compared with whip-like movements [17] or throwing movements [18]. Nevertheless, none of these studies included a comparison of the two roundhouse kick versions and their kinematics.

The aim of this study was to obtain knowledge about kinematic indicators that determine the effectiveness of roundhouse kicks (in taekwon-do terminology, *dollyo chagi*) in two versions: sport and traditional. This aim is based on the analysis of biomechanical premises to use different technique patterns and its practical assessment for sports competitions and self-defense. The detailed aim was formed by specific research questions using the criteria of biomechanical analysis in Taekwon-do [5,19,20]:

(1) What are the differences in the execution time and maximal velocity values of the feet between the sport and the traditional version of the roundhouse kick?

(2) What are the differences between the kinematic indicators of the preferred and non-preferred lower limbs during the roundhouse kick execution?

(3) Does lower limb length affects chosen kinematic variables of kicking foot?

The answers to the following questions are concurrent with the ongoing trends in sports biomechanics for martial arts. The applicability of this study is to provide recommendations for practitioners and trainers to optimise their technical performance and improve training methods. Such an analysis is required to supplement traditional types of martial art training through scientific, evidence-based recommendations. Teaching faster, stronger, and more precise strikes is crucial in sports competitions. A comparison of these two versions will contribute to a better understanding of the benefits and differences between sports and traditional versions in potential use for self-defense.

2. Materials and Methods

2.1 Subjects

Study group was composed of 15 adult males (age: 21.9 ± 6.8 years; body mass: 71.1 ± 11.5 kg; height: 175.7 ± 8.4 cm) who are taekwon-do ITF (International Taekwon-do Federation) masters. This group included athletes who obtained championships during Polish and European championships. Their experiences lasted for at least four years. All participants were trained three to five times per week. The inclusion criteria were as follows: minimal age of 18 years, mastery level of at least 1st gup (red: one degree before black belt), and above (black belts). The study was conducted at the Polish-Japanese Academy of Computer Technology in Bytom using the Human Motion Lab setup. All participants were informed of the procedures and provided written consent for participation in this study.

2.2 Protocol

The study was conducted at the Human Motion Laboratory. This setup is composed of 10 infrared cameras (NIR Vicon MX-T40) with a resolution of 4 megapixels (2352 × 1728 pixels), a 10-bits grey scale. The system captured images at a frequency of 370 frames per second at full resolution.

The system captured the motion of the marker placed on the participant's foot and registered its placement on the X, Y, and Z axes. The resultant velocity of the marker was computed using Microsoft Excel with Euclidean vector norms. The moment of movement initiation was determined by mathematical assessment of the velocity curve with the assistance of the Mokka software (version 0.6.2., powered by the open-source library Biomechanical ToolKit (BTK) Copyright © Arnaud Barré, 2011–2013), which allows the analysis of the visual representation of the captured data. The end of the technique was set for a point where a 0 m/s value was reached for the X-axis. Using these methods, the time of technique execution and maximal velocity of the kick were obtained. Lower limb length was computed as the distance between the hip and ankle markers.

During the motion capture, the participants kicked three times for each set. The first set was for the traditional side stance (in taekwon-do terminology—*niunja sogi palmok debi maki*) and sports stance, which are individual and characteristic for specific participants. All kicks were performed for both lower limbs with the rear kicking side, without any physical target. There was no start signal set and the participants started individually. The only command was to kick as fast and best as they could. A database of 180 kicks was obtained (two versions × two legs × three trials × 15 participants).

2.3 Statistical Analysis

The kinematic variables obtained were subjected to classical descriptive analysis. The mean, standard deviation, and minimal and maximal values were calculated.

Due to the lack of normal distribution, differences between groups were computed using analysis of variance (ANOVA). The relationships between the chosen variables were verified using Pearson's correlation analysis. Statistical significance was set at $p < 0.05$. All computations were performed using the IBM SPSS Statistics for Windows, Version 20.20 (IBM Corp., Armonk, NY, USA).

3. Results

Table 1 contains visual assessment and expert knowledge about the differences between the traditional and sports versions of roundhouse kick execution. Through this summarisation, changes in versions are observed in the initiation phase, which causes further kinematic differences between the versions. Another difference is seen during the contact phase, where the contact area of the traditional version is for the sole site of the foot and for the sport version is the dorsal site. A graphical interpretation of the tested kicks and example graphs of foot velocity during kick execution (red line for the sport version and blue line for the traditional version) are presented in Fig. 1. Differences in the shape and duration of each kick were evident for the two versions.

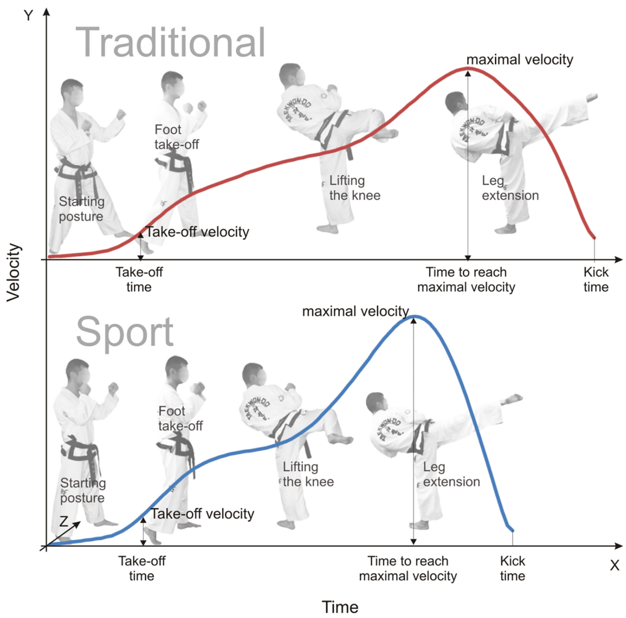

Fig. 1. Example graphs of foot marker velocity changes in time in both analysed versions—sport (red line) and traditional (blue line) with division for movement phases.

The mean registered values of the computed indicators with divisions of the right and left legs are presented in Table 2. In Table 3, the mean values of maximal velocity and time of execution are presented alongside the computed statistical differences between those variables. The results showed that maximal velocities and execution time for the right and left legs indicated significant differences ($p < 0.01$) depending on the kick version but did not reveal significant differences for the kick side.

Table 4 presents correlation coefficients between chosen kinematic variables for sport and traditional version of roundhouse kick. The shorter time of foot take-off (r = 0.70; $p < 0.05$—sport version and r = 0.81; $p < 0.01$—traditional version); time of reaching maximal velocity (r = 0.93; $p < 0.05$—sport version and r = 0.98; $p < 0.01$—traditional version), the shorter is time of roundhouse kick execution. There is moderate correlation between maximal velocity of a kick and time of its execution (r = 0.55; $p < 0.05$—sport version and r = 0.57; $p < 0.01$—traditional version). Weak correlation was observed for foot take-off velocity and maximal velocity of a kick (r = 0.34; $p < 0.05$—sport version and r = 0.08; $p < 0.01$—traditional version). For both presented version, there is negative correlation between time of kick execution and maximal velocity value.

Table 5 presents correlation coefficient values between lower limb length and maximal velocity and time of kick execution. There was no significant correlation between those variables.

4. Discussion

The research showed that there was a significant difference between the registered kinematic indicator values between the two analysed versions of the roundhouse kick. Data analysis suggests that the roundhouse kick in the sports version reaches higher maximal velocities than its traditional version ($p < 0.01$) (Table 2). The obtained values of maximal velocity (from 12 m/s to 16 m/s) for the sports version are concurrent with the findings of other authors [21–23]. The obtained values of maximal velocity for the traditional stance are also lower in the findings of other authors, with a mean value around 11–11.5 m/s [9]. Moreover, kick execution time was shorter for the sports version ($p < 0.01$). This is justified by the fight and sparring environment in which athletes need to surprise opponents with sudden movements. Surprises may cause a delayed opponent response, making him unable to act accordingly. The maximal velocity is associated with higher power and force generated by the lower limbs [24].

Traditional roundhouses are used in patterns competitions or strength tests. In such cases, there is no dynamic opponent that the athlete must adjust. Therefore, the time of technique execution is not as important as that during combat, as no one will fight back. The lower limb segment trajectory during roundhouse kick execution is circular. From a physics perspective, every rotational movement depends on the distance from the rotation axis. The larger the radius, the higher the force generated [25]. Despite these dependencies, the results of this study show that the length of the lower limb did not correlate with the maximal velocity of a kick or with the time of execution.

The results of the research showed no significant differences in the maximal velocity between the kicking sides.

Table 1. Descriptive comparison of movement phases of roundhouse kicks in traditional and sport version.

<table>
<tr><th>Movement phase</th><th>Traditional version</th><th>Sport version</th></tr>
<tr><td>Initial stance (this includes initial position and posture before beginning of technique execution)</td><td>Participant is taking side stance with one leg to the front. Heel of one foot is aligned with toes of another. Both knee joints are flexed. In taekwon-do terminology it is called: niunja sogi palmok debi maki. According to the rules [1] in this stance 70% of body weight should be on the rear leg and 30% on the front leg. Participant is preparing for technique execution. Hands are hold still. Time is spent for Focus in order to perform accurate and precise movement.</td><td>Participant is taking side stance with one leg to the front. Heel of one foot is aligned with toes of another. Both knee joints are flexed. Participant is preparing to strike. Whole body is making spontaneous movements during preparation. Time is spent for Focus in order to perform accurate and precise movement.</td></tr>
<tr><td>Foot take-off</td><td colspan="2">Participant is shifting body weight to front leg and rotate body with arms in opposite direction to kicking leg. Kicking leg foot is taking off the ground, placing all body weight on the front leg. Upper limb swing movements is making additional rotation, increasing velocity of the trunk, and kicking leg.</td></tr>
<tr><td rowspan="2">Lifting the knee</td><td colspan="2">With foot take-off, lower limb rising phase is starting. Lower limb is risen by hip flexion with knee flexion. Hip rotation is setting foot on the right trajectory towards the target.</td></tr>
<tr><td>Contact area is sole side of the foot, right under toes. Toes makes dorsal flexion, so metatarsal part of feet is connecting to the target. According to taekwon-do terminology it is called ap kunchi.</td><td>Dorsal part of feet contacts a target. According to taekwon-do terminology it is called baldung.</td></tr>
<tr><td>Leg extension</td><td colspan="2">Kicking leg is making knee extension. Upper limbs made counterrotation to maintain balance, avoiding full body rotation.</td></tr>
</table>

Table 2. Descriptive statistics of kinematic indicator values with division for both kicking legs and versions.

Version	Variable	Leg	Min	Max	Mean	SD
Sport	Time of execution (s)	Left	0.35	0.57	0.45	0.07
		Right	0.34	0.67	0.46	0.09
	Time of reaching maximal velocity (s)	Left	0.23	0.50	0.36	0.07
		Right	0.27	0.60	0.38	0.08
	Maximal velocity (m/s)	Left	8.40	16.20	12.26	1.95
		Right	8.70	16.50	12.44	1.95
	Foot take-off time (s)	Left	0.07	0.18	0.12	0.03
		Right	0.06	0.26	0.12	0.04
	Velocity of foot take-off (m/s)	Left	0.53	3.65	1.51	0.56
		Right	0.61	2.49	1.36	0.45
Traditional	Time of execution (s)	Left	0.37	0.73	0.53	0.09
		Right	0.36	0.78	0.54	0.09
	Time of reaching maximal velocity (s)	Left	0.28	0.64	0.44	0.09
		Right	0.29	0.70	0.46	0.09
	Maximal velocity (m/s)	Left	8.10	15.80	11.08	1.88
		Right	7.50	15.80	11.28	1.77
	Foot take-off time (s)	Left	0.04	0.28	0.14	0.06
		Right	0.07	0.32	0.15	0.05
	Velocity of foot take-off (m/s)	Left	0.04	2.53	1.12	0.53
		Right	0.47	2.43	1.15	0.40

Min, minimal value; Max, maximal value; SD, standard deviation.

This could be interpreted within the scope of the taekwon-do training methodology. The effect of the polishing dynamic structure of the motor habit during training is realised by increasing the motor task difficulty and forcing motor excellence in both preferred and non-preferred legs. From the beginning of the taekwon-do practice, a similar emphasis is placed on teaching techniques for both sides of the body. Although lateralisation is a commonly known phenomenon in physical training, at the master's level in taekwon-do, these differences were not significantly different. This phenomenon was not unique to the results of the present study. Numerous authors who studied martial arts obtained similar results, which proved that lateralisation did not occur during their analysis [26–31]. Those authors analysed the impact of executing motor tasks with increased complexity or the teaching effects of different mo-

Table 3. Mean values of maximal velocity and time of execution of roundhouse kick in different versions.

Version	Maximal velocity (m/s) $\bar{x} \pm$ SD Left leg	Maximal velocity (m/s) $\bar{x} \pm$ SD Right leg	SS	Time of execution (s) $\bar{x} \pm$ SD Left leg	Time of execution (s) $\bar{x} \pm$ SD Right leg	SS
Sport	12.26 ± 1.95	12.44 ± 1.95	F = 0.51 p = 0.48	0.45 ± 0.74	0.46 ± 0.90	F = 0.03 p = 0.84
Traditional	11.08 ± 1.88	11.28 ± 1.77	F = 0.71 p = 0.40	0.53 ± 0.09	0.54 ± 0.09	F = 0.42 p = 0.51
SS	F = 8.92; ***p* = 0.001**	F = 8.73; ***p* = 0.001**	–	F = 15.93; ***p* = 0.001**	F = 18.61; ***p* = 0.001**	–

SS, statistical significance; $\bar{x}$, mean; SD, standard deviation; F, Fisher's statistics; p, significance value; bold, results are statistically significant.

Table 4. Correlation table between chosen kinematic variables for roundhouse kick.

Version	Variable	Time of execution (s)	Time of reaching maximal velocity (s)	Maximal velocity (m/s)	Foot take-off time (s)
Sport	Time of reaching maximal velocity (s)	**0.929****	—		
	Maximal velocity (m/s)	**–0.551****	–0.419**	—	
	Foot take-off time (s)	**0.703****	**0.729****	–0.235*	—
	Velocity of foot take-off (m/s)	–0.449**	–0.403**	0.341**	–0.212*
Traditional	Time of reaching maximal velocity (s)	**0.984***	—		
	Maximal velocity (m/s)	**–0.575***	–0.509*	—	
	Foot take-off time (s)	**0.810***	**0.799***	–0.322*	—
	Velocity of foot take-off (m/s)	–0.118	–0.144	–0.081	0.060

*Significance level at $p < 0.01$; ** Significance level at $p < 0.05$; Bolded, moderate to strong correlations.

Table 5. Correlation table between kinematic indicators and lower limb length.

Variable	Leg	Technique version	Lower limb length
Maximal velocity (m/s)	Left	Sport	0.386*
		Traditional	0.238
	Right	Sport	0.290
		Traditional	0.145
Time of execution (s)	Left	Sport	0.144
		Traditional	0.027
	Right	Sport	0.183
		Traditional	0.187

*Statistical significance at $p < 0.05$.

tor skills. Besides the benefits on the motor level, taekwon-do training has been proven to increase self-control abilities and learn other complex motor tasks [32–35]. Practitioners are also better at predicting opponent movements and have better decision-making capabilities [36]. Bilateral communication of the body is one of the reasons why physiotherapists or fitness trainers may consider the recommendation of taekwon-do for their clients as a beneficial form of exercise, which may help in general body development [37]. Uniform, bilateral development could also be explained by proper muscle fascia movement, which acts as an energy transmission network for mechanical forces throughout the body [38]. Studies shows, that taekwon-do athletes are characterized by especially hight neuromuscular system activity of lower limbs [39–41].

The sample size of this study was the main limitation. This study could be improved by measuring the strike force and electromyographic analysis to better understand these differences. In addition, some authors have compared novice and expert athletes and their performance during roundhouse kick execution [14,42], which could contribute to the body of knowledge. Nevertheless, these findings should serve as a background for further research on the biomechanics of the martial arts.

This study proves that trainers should emphasise speed and accuracy training for sports versions of roundhouse kicks. The results show that kick time is shorter and more effective in combat situations. Therefore, for self-defense purposes against moving opponents, coaches should skip traditional versions of techniques to facilitate proper reflexes for their students. However, traditional versions of these techniques should not be abandoned. Its use in strength tests and breaking boards, instead of sport versions, proves its high effectiveness and distribution of generated power towards inanimate objects [43], where moving and timing are not crucial for victory. Such benefits could be used in emergency situations when someone is required to force open doors or move obstacles to preserve the health or life of an individual.

5. Conclusions

We confirmed our assumptions that there are significant differences between sports and traditional versions in terms of the maximal velocity of a kick and the time of its execution. The differences in technique execution can be justified by their purpose and effectiveness. In a fight, opponents compete for the points; therefore, faster reactions and shorter strikes are desirable to succeed. Traditional versions are used in competition formulas without opponents; therefore, the full form can be maintained without any external disturbances. Lower limb length does not influence the velocity or time of kick execution.

The obtained data allowed us to conclude that harmonious bilateral motor development of male taekwon-do masters, which was confirmed by the lack of significantly different results for the tested kinematic indicators for the preferred and non-preferred legs.

Author Contributions

JW and TG designed the research study. JW and TG performed the research. DO, MC, JL provided help and advice. JW, TG, DM and DO analyzed the data. JW, TG, DM, DO, MC and JL wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

This The Human Subjects Research Committee of the host University scrutinized and approved the test protocol as meeting the criteria of Ethical Conduct for Research Involving Humans (Bioethics Committee at the University of Rzeszów, No. 2/6/2017). All subjects in the study were informed of the testing procedures and voluntarily participated in the data collection.

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Conflict of Interest

The authors declare no conflict of interest.

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